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Perception of an Illusory Form Under Conditions of Limited Visibility

By

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Ambiguous figures and visual illusions are difficult to perceive when presented in terms of color contrast rather than luminance contrast. This finding has prompted the notion that the perception of these forms depends primarily on processing along an achromatic, luminance pathway. Others contend that the perception of such figures depends on the visibility of the stimulus rather than on the particular pathway traversed from eye to brain. If visibility is a limiting factor on perception, then it would be useful to determine how certain perceptual ambiguities are resolved under various conditions of limited visibility. In the present study, visual perception of a complex, ambiguous form was evaluated under several conditions of limited visibility including equiluminant color contrast (S and LM) and a range of luminance contrasts, also were evaluated. The results confirm and extend previous findings in showing that the perception of a complex, illusory form depends more on the visibility of the stimulus than on the particular pathway accessed. The expectations and prior experience of the observer also were found to be crucial determinants of complex object recognition.

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Table of contents

List of figures

Introduction

Early stages of visual processing occur along separate pathways which are distinguished anatomically, physiologically, and functionally (Lennie, 1980; Krauskopf, Williams & Heeley, 1982; Derrington, Krauskopf, & Lennie, 1984; Livingstone and Hubel, 1987, 1988; De Yoe & Van Essen, 1988; Schiller, Logothetis, & Charles, 1990). While these pathways differ along a number of dimensions including contrast sensitivity, spatial frequency tuning, and motion detection (Schiller et al.), the most common approach for distinguishing between separate pathways is to present stimuli at equiluminance such that there is no variation in effective intensity, but only in color. Equiluminant stimuli are relatively ineffective for the pathway which responds exclusively on the basis of luminance contrast (Lee & Martin, 1989). Stimulation is limited largely to chromatic pathways, and different equiluminant color directions (e.g., LM cone and S cone) can distinguish between separate color channels (Krauskopf et al.; Derrington et al.).

Several classes of visual illusions and ambiguous figures are difficult to perceive when presented in terms of (equiluminant) color contrast as compared to luminance contrast. This finding has prompted the notion that the perception of such forms depends primarily on processing along the luminance pathway (Livingstone & Hubel, 1987; 1988). Others contend that color sensitive pathways, which also can process luminance contrast, support the perception of several illusions (Ingling & Grigsby, 1990). It has also been suggested that the perception of illusory or ambiguous forms depends more on the visibility of the stimulus than on the particular pathway traversed from eye to brain (Rabin, Adams, & Switkes, 1992). If visibility imposes fundamental limits on recognition, then it would be useful to determine how certain perceptual ambiguities are resolved under real-world conditions of limited visibility. In the present study, visual perception of a complex, ambiguous form (a figure depicted in three dimensions by illusory contours) was evaluated under several conditions of limited visibility including equiluminance (LM and S directions), attenuated luminance contrast, and an isochromatic condition of low luminance similar to what is seen through night vision goggles (NVGs). The results confirm and extend previous findings in demonstrating that the perception of a complex, illusory form is constrained by the visibility of the stimulus, rather than by the particular pathway traversed from eye to brain. For the illusion studied, perceptual experience and expectation also were found to be important determinants of object recognition.

Methods

Fifteen adult volunteers (age 22-46; mean=32 years) participated in the main experiment on target recognition. Five subjects were tested on a contrast matching task to help validate the color and luminance contrast of the displays. Subjects with refractive error wore their glasses or contact lenses during testing. Informed consent was obtained after protocol approval through our scientific review process.

Stimuli were software-generated on a Zenith ZCM-1 VGA color monitor. Temporal presentation, contrast, and chromaticity were under computer control. Luminance was measured with a calibrated photometer (Minolta LS-100 and CS-100) and stored in tabular form. The color space of MacLeod and Boynton (1978), as later modified by Krauskopf et al. (1982) and Derrington et al. (1984), was used as a basis for generating stimuli along two equiluminant color (LM and S) and one achromatic luminance direction. Modulations in the three different directions (LM, S, and luminance) were produced about a common, achromatic mean level of stimulation (13.4 fL; $x=0.30$, $y=0.34$). The separate color directions (LM and S) were identified empirically for one observer by using a chromatic adaptation approach described by others in the literature (Verdon & Adams 1987; Webster et al., 1990; Rabin & Adams, 1992). Modulation along the luminance axis was achieved by varying the intensity of the three guns symmetrically, and quantified as a Weber contrast (background-stimulus/background luminance). Because the visual display in NVGs is green and isochromatic (P20 or P22 phosphor), only the green gun of the color monitor was used to simulate the night environment as seen through NVGs. The screen luminance for this condition was reduced to 0.6 fL and the contrast was 27 percent to be comparable to an NVG display under moderate night sky conditions (Rabin, 1993).

The stimulus was an illusory tank defined by portions of circles ("Pac-men") arranged so that the tank appeared three-dimensional (Fig. 1). The tank subtended an angle of approximately 8.5° at a viewing distance of 1 m.

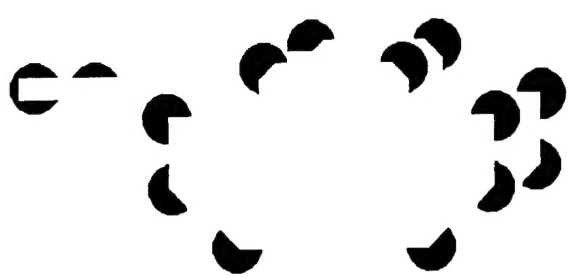

Figure 1. The illusory tank used in the present experiment. The luminance and chromaticity of the components and background were varied to produce different viewing conditions including simulated NVG, equiluminant LM and S, and various luminance contrasts.

In the main, target recogntion experiment, the tank was to be presented under three conditions assumed to be limited in visibility (NVG, LM, and S). It was desired that the tank be equally visible in each condition so that differences between responses to these conditions could not be attributed to differences in visibility. This was achieved by presenting the "Pac-men" components of the S and LM tanks at the same level above detection threshold which corresponded to the maximum available color contrast along the S direction, but a reduced contrast along the LM direction. In addition, a suprathreshold, contrast matching procedure was conducted on five subjects to verify levels of equal visibility. Two tanks, one above the other, were displayed on the monitor. The bottom tank was depicted in achromatic, luminance contrast which could be varied from 8 to 44 percent by keyboard control. The top tank was presented in each of the three other conditions to be used in the main experiment (NVG, LM, and S). For each condition, the subject adjusted the contrast of the bottom tank until it appeared equal in visibility to the top tank. Subjects were told to use both the visibility of the illusory form and the clarity of its components to match the tanks. Three matching contrasts were obtained from each subject at each of the three viewing conditions. A repeated-measures ANOVA revealed no significant difference in the luminance contrast which matched the NVG, LM, and S displays ($F_{3,16}=1.91$, $p>0.14$) indicating that they were about equal in visibility. The mean matching contrast across all conditions was 16.4 percent (8.6 percent Michelson contrast).

In the main experiment, the subject was seated comfortably before the display and told that an image would appear on and off. Each time the image appeared (the illusory tank), they were to describe what they saw. Each trial began with a uniform field for 10 seconds which then was replaced by the illusory tank for 3 seconds This sequence was repeated until each condition (NVG, LM, S, and four luminance contrasts ranging from 8 to 100 percent in 2.9x steps) was presented. The direction of the tank was alternated (left or right) from trial to trial. The NVG test field was preceded by a uniform field at the NVG luminance (0.6 fL), and each of the other conditions was preceded by a uniform field at the mean luminance of the chromatic and luminance displays (13.4 fL). If a subject did not recognize the tank during the sequence of presentations, then the tank was presented again, with no time constraint, at maximum luminance contrast. If the subject failed to perceive the illusory form, then he was prompted to look for a military figure.

Results

Figure 2 shows the percentage of subjects who recognized the tank under each viewing condition. Only about 1/3 of all subjects could recognize the illusory tank under conditions of limited visibility including NVG, equiluminance, and reduced luminance contrast. Of the five subjects who perceived the tank under these conditions, four had considerable prior training identifying military figures, and one was a trained

psychophysical observer. Thus, none of the naïve subjects perceived the illusory tank under conditions of limited visibility regardless of the condition or pathway utilized to perceive the form. As luminance contrast was increased, the number of subjects who perceived the tank increased indicating the importance of contrast for recognition of this complex, ambiguous form. However, even at high contrast, several subjects did not perceive the tank until given unlimited viewing time and/or prompted to look for a military form. Thus, for this complex illusion, perceptual set was a crucial determinant of object recognition.

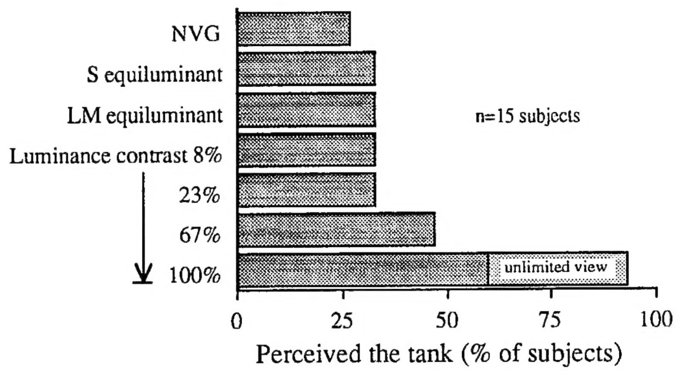

Figure 2. The percentage of subjects (n=15) who perceived the illusory tank under different viewing conditions (NVG, equiluminant S, equiluminant LM, and luminance contrast ranging from 8 to 100 percent). The additional subjects who perceived the tank at maximum luminance contrast with unlimited viewing time are also indicated.

Discussion

This study confirms previous reports that visual illusions and ambiguous figures are difficult to perceive when presented in terms of chromatic contrast. It also demonstrates that recognition of an illusory form can be equally impaired in other conditions of limited visibility such as the night environment as seen through night vision goggles. A complex, illusory form presented at a low luminance contrast is no more recognizable than one presented at equiluminance or under simulated NVG conditions. Recognition of a complex, illusory form is constrained by the visibility of the stimulus, rather than by the particular pathway utilized from eye to brain.

Although stimulus visibility imposes fundamental limits on form perception, the expectations and prior experience of the observer also are important determinants of complex object recognition. The subjects who recognized the illusory tank had extensive past experience identifying military vehicles or equipment. Some subjects who were otherwise naïve and had difficulty recognizing the tank were able to do so only when prompted to perceive a military figure.

That few observers recognized the tank under simulated NVG conditions underscores the fact that the visual environment can be limited through image intensifiers. Despite substantial intensification of the image and the ability to see in the dark, these devices present an isochromatic view of the world lacking in contrast and detail. The user must compensate for these deficiencies with training, vigilance, and experience. Object recognition in a degraded visual environment initially is limited by the visibility of the stimulus, but ultimately determined by the perceptual expectation, vigilance, and experience of the observer.

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